Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 91 (2014) 435 – 440
Procedia Engineering
www.elsevier.com/locate/procedia

XXIII R-S-P seminar, Theoretical Foundation of Civil Engineering (23RSP) (TFoCE 2014)

Analysis of Mechanical Properties of Concrete of Frozen and Unfrozen Specimens

Miroslav Brodnan[a]*, Frantisek Bahleda[a] , Peter Kotes[a]

[a] *University of Zilina, Faculty of Civil Engineering, Univerzitna 8215/1, Zilina 010 26, Slovakia*

Abstract

In term of practical applications, it is important to know how to change the modulus of elasticity of concrete, which is in wintertime exposed to low temperatures. Presented are the partial results of research oriented on monitoring the changes of the values of modulus of elasticity in time of frozen and unfrozen concrete specimens.

Peer-review under responsibility of organizing committee of the XXIII R-S-P seminar, Theoretical Foundation of Civil Engineering (23RSP)

Keywords: compressive strength; modulus of elasticity; concrete; unfrozen specimen; frozen specimen.

1. Introduction

The modulus of elasticity is a basic mechanical characteristic of concrete. Significantly affects the deformation properties of concrete and hence the deformations of concrete, reinforced concrete and prestressed structures, such as deflections, displacements, strain etc. The general rule is, the greater the modulus of elasticity of the concrete the lower its deformations and the vice versa. With arising modulus of elasticity, deformation of concrete and deflections of structures are reduced. Despite the great importance of the elasticity modulus of concrete for deformation behaviour of reinforced concrete structures is subject to the exceptions given minimal attention to this characteristic of concrete in the design phase and also in the realization phase.

In the design of new structures is in static calculation considering the modulus of elasticity, but mostly it is the use of standard (tabulated) values. These tabulated values do not correspond to real values, which are in fact achieved in practical applications.

* Corresponding author. Tel.: +421-41-5135669; fax: +421-41-5135690.
E-mail address: brodnan@fstav.uniza.sk

Peer-review under responsibility of organizing committee of the XXIII R-S-P seminar, Theoretical Foundation of Civil Engineering (23RSP)
doi:10.1016/j.proeng.2014.12.017

Taking into account the standard values of the elasticity modulus derived for each class of concrete is therefore currently inadequate. When structures are susceptible to achieve large deformations is therefore appropriate to propose also the elasticity modulus and put it into concrete specification.

In terms of practical applications, it is also important to know how the value of the modulus of elasticity of concrete will change, which can be in the winter time exposed to low temperatures even at the time of setting and hardening of concrete in structure.

2. Experimental measurements

2.1. Influence of fresh concrete composition on modulus of elasticity

In design and production of experimental specimens it shall be taken into account that the value of the modulus of elasticity is affected by the quality of the used components and their relationship, regardless of whether the concrete is exposed in the early days to ideal or extreme conditions (e.g. low or minus temperatures). If quality natural aggregate will be used, then it will always have a higher modulus of elasticity than the hardened cement stone. The resulting elasticity modulus of concrete should be between elasticity modulus of aggregate and cement stone.

2.2. Determination of static modulus of elasticity of concrete

In determining the static modulus of elasticity in compression, we proceeded in accordance with STN ISO 6784 [1]. For the realization of the elasticity modulus tests eight of concrete beams with dimensions 100 x 100 x 400 mm were prepared (Fig. 1.). For the production of specimens the concrete STN EN 206-1 - C 30/37 - XC4, XD3 (SK) - Cl 0.4 - D_{max}16 - S3 [2] was used. The Portland cement CEM I 42.5 R (Cement Hranice) and mined aggregate (river gravel) fraction 0-4, 4-8 and 8-16 mm were used.

Fig. 1. Test specimens.

Specimens were stored and treated in the laboratory. After three days, the specimens were formed and the fourth day was on two specimens (I-4, II-4) measured the modulus of elasticity.

The four specimens were stored for 28 days in the freezer at - 15 °C. Subsequently on two of them (MI-28, MII-28) was measured the modulus of elasticity. At the same time the measurements were carried out also on two unfrozen specimens (I-28, II-28).

Recent measurements of elasticity modulus were made on two specimens (MI-28-28, MII-28-28), which were 28 days in the freezer and after removal were next 28 days stored in a laboratory environment.

To determine the compressive strength of concrete and the high load stress (1/3 of maximum stress) eight other specimens (concrete beams with dimensions 100 x 100 x 400 mm) were prepared. Compressive strength f_c was calculated according to the formula [3]:

$$f_c = \frac{F}{A_c} \tag{1}$$

where: f_c is compressive strength [N . mm^{-2}],
F is maximum compression force [N],
A_c is cross-sectional area of specimen [mm^2].

Actual measurement of the elasticity modulus of concrete was realized by extensometer with digital indicator (with a measuring base 200 mm) and at the same time was also used strain-gauge apparatus SPIDER 8 with strain gauges 1-LY41-50/120. Both measurement methods were compared in the evaluation. Length variations for both methods were measured on the two opposite sides of each specimen.

After centering of test specimen in the testing machine (Fig. 2.) the basic stress σ_b was applied and values of force and strain were continuously recorded. At an uniform speed, the stress increased to a value σ_a (1/3 of the maximum stress). Maintaining the prescribed stress (for 60 seconds) on the value σ_a, the load reduced to basic stress σ_b the same way as during the loading of the specimen. Then two more identical loading cycles were made. After the last load cycle and maintain the stress on the value σ_b the specimen to be loaded again on the value σ_a, and subsequently the loading of the specimen increasing until to failure.

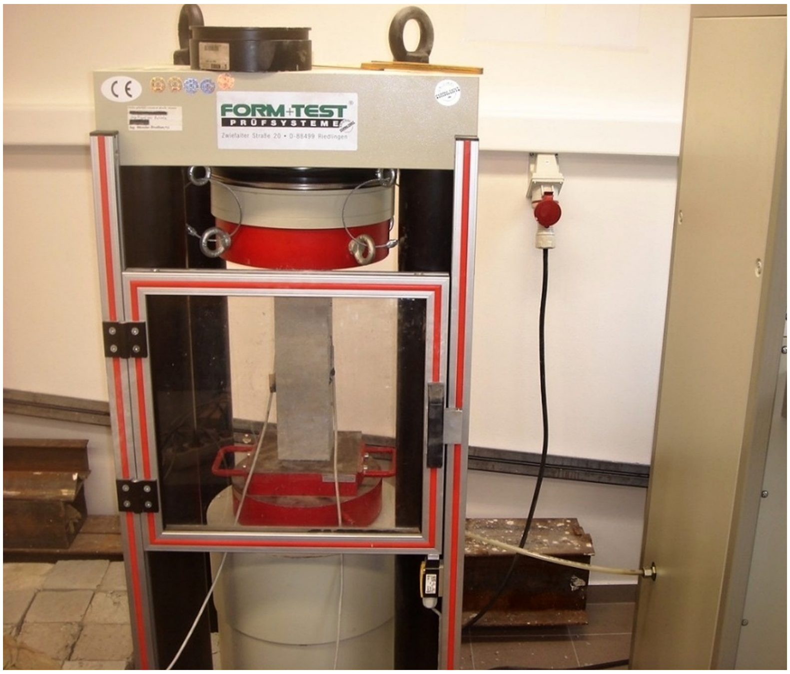

Fig. 2. Test specimen in the testing machine.

Static modulus of elasticity E_c was calculated according to the formula [1]:

$$E_c = \frac{\Delta \sigma}{\Delta \varepsilon} = \frac{\sigma_a - \sigma_b}{\varepsilon_a - \varepsilon_b} \tag{2}$$

where: E_c is the static modulus of elasticity [N . mm^{-2}],
σ_a is the high loading stress [N . mm^{-2}],
σ_b is the basic stress [0.5 N . mm^{-2}],
ε_a is the average strain in the high loading stress [-],
ε_b is the average strain in the basic stress [-].

The average strains ε_a and ε_b have been calculated from all measured places in a particular load cycle.

2.3. The measurement results

The results of measuring the compressive strengths (Fig. 3.) and elasticity modulus of the beams (Fig. 4.), determined by an extensometer with digital indicator (0.001 mm graduations) and a strain-gauge apparatus SPIDER 8 with strain gauges 1-LY41-50/120, are shown in Table 1.

Table 1. Compressive strength f_c and modulus of elasticity E_c of frozen and unfrozen specimens.

Specimen identification	Compressive strength f_c [N . mm^{-2}]	Modulus of elasticity E_c (by extensometer) [N . mm^{-2}]	Modulus of elasticity E_c (by strain gauges) [N . mm^{-2}]	$f_{c(i)}/f_{c(I-28)}$	$E_{c,def(i)}/E_{c,def(I-28)}$	$E_{c,tenz(i)}/E_{c,tenz(I-28)}$	$E_{c,def(i)}/E_{c,tenz(i)}$
I-4	22.7	26 700	26 900	0.596	0.812	0.805	0.993
II-4	20.8	26 300	27 200	0.546	0.799	0.814	0.967
I-28	38.1	32 900	33 400	1.000	1.000	1.000	0.985
II-28	39.6	30 900	31 300	1.039	0.939	0.937	0.987
MI-28	30.7	23 500	24 800	0.806	0.714	0.743	0.948
MII-28	30.6	22 100	22 600	0.803	0.672	0.677	0.978
MI-28-28	40.5	25 900	27 100	1.063	0.787	0.811	0.956
MII-28-28	42.0	26 400	27 800	1.102	0.802	0.832	0.950

From the results shown in Table 1 it is seen, that the modulus of elasticity of frozen beams (MI-28, MII-28) get markedly lower values (28.5 to 32.8 % less) as the modulus of elasticity of unfrozen beams (I-28, II-28). The difference of the compressive strengths between these specimens is also quite strong against frozen specimens (19.4 to 19.6 %).

For specimens (MI-28-28, MII-28-28), which were after 28 days long frozen stored for 28 days in the laboratory, compared to specimens frozen for 28 days (MI-28, MII-28), we can see an increase of elasticity modulus and also quit a significant increase in compressive strength.

Modulus of elasticity of frozen beams, which were stored for 28 days more in the laboratory (MI-28-28, MII-28-28) get lower values (19.7 to 21.2 % less) as modulus of elasticity of unfrozen beams (I-28, II-28). The difference between the compressive strength of these specimens is negligible.

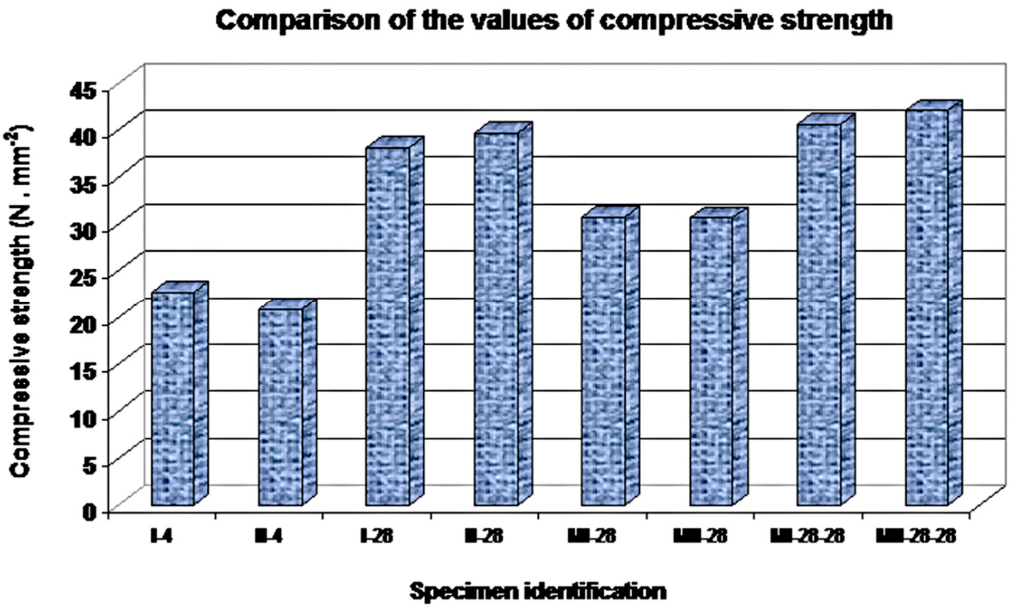

Fig. 3. Results of measuring the compressive strength.

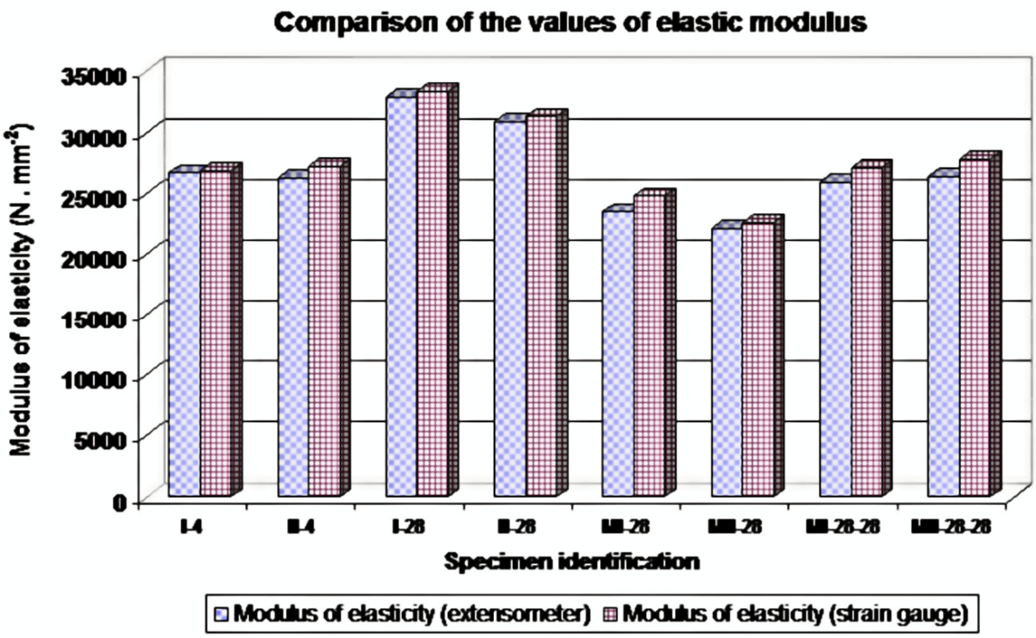

Fig. 4. Results of measuring the modulus of elasticity.

The difference between the resulting values of elasticity modulus determined by extensometer with digital indicator and by strain-gauge apparatus SPIDER 8 with strain gauges 1-LY41-50/120 is up to 5 %.

3. Summary

Theoretical assumptions are a good basis for design of fresh concrete compound, but even their completion cannot ensure assumed achievement of desired elasticity modulus value. A wide variety of used input components and types of concrete indicates differences in achieved results of modulus of elasticity [4]. For this reason, it is necessary to consider the modulus of elasticity already during the design of fresh concrete. For manufacturers of concrete thence it follows a need to individually verify the elasticity modulus for each manufactured concrete (for example, in the realization of important engineering constructions, concrete application in extreme summer or winter condition, etc.), if required, regardless of the similarity in composition with other concrete.

The presented results show, that the value of the static modulus of elasticity and compressive strength of the concrete can markedly vary by the action of low temperatures. This situation in practical applications can occur e.g. when concrete is placed in construction in winter even in the time of setting and hardening.

In other planned experimental measurements will be interesting to watch the changes of modulus of elasticity and compressive strength also for the various strength classes of concretes of various compositions (cement, aggregate, water-cement ratio, the use of admixtures, additives, etc.). Also, we will monitor the changes of modulus of elasticity of frozen and unfrozen specimens in the long-time.

Acknowledgements

This article came to existence thanks to support within the frame of OP Education for project "Support of quality of education and research for area of transport as an engine of economics, (ITMS: 26110230076), which is co-financed from sources of European Social Fund and by the Slovak Research and Development Agency under contract No. APVV-0106-11.

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